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REVIEWS.

VAN HISE'S "PRINCIPLES OF PRE-CAMBRIAN GEOLOGY."

For some years investigators and teachers of dynamic geology have needed a revision of the theories of Dana, Fisher, Reade, Dutton, Kelvin, and others, with reference to rock deformation. The publications of Van Hise are a contribution to such a revision, and other articles in preparation by him may probably summarize existing knowledge and current theory in a form, which will be a material advance.

By training, experience, and bent of mind, Van Hise is fitted for the task. As assistant and successor to Irving in the geologic investigation of the Lake Superior iron region, he has solved the most difficult problems of the older rocks. In microscopic petrography of the crystalline schists and allied formations he is a leading authority. In obscure stratigraphy and complex structural relations he has had much experience. His base of observation has been broadened to include all important districts from the Pacific to the Atlantic, and the classic localities of Europe.

The *Principles of Pre-Cambrian Geology* is a work intended "(1) to give a partial discussion of principles applicable to geological work among the pre-Cambrian rocks of North America, and (2) to give an historical account of the North American pre-Cambrian, and to point out the principles illustrated in the various regions."

In Part I the author discusses (1) movements of rock materials under deformation, (2) analysis of folds, (3) cleavage and fissility, (4) joints, (5) faults, (6) autoclastic rocks, (7) metamorphism of the sedimentary rocks, (8) metamorphism of the igneous rocks, (9) phenomena of stratigraphy.

Part II describes the facts of historical geology in general for the Archæan and Algonkian periods, and in particular for ten districts of the United States and Canada in which rocks of these ages occur. There is an appendix on " Flow and Fracture of Rocks as Related to

Structure," by Leander Miller Hoskins, who treats the subject by mathematical analysis.

In 1878 Heim published his discussion of "Umformung durch Bruch and Umformung ohne Bruch."[1] It was necessary less than twenty years ago that he should present an elaborate argument to show that without the action of any softening agent rocks might be deformed without fracture under appropriate mechanical conditions. He had seen and understood qualitatively the facts of folded strata. Van Hise carries the interpretation to quantitative expression in terms of pressure per square inch dependent on depth beneath the earth's surface. Following Heim, and going further than he did, Van Hise formulates three principles:

(1) Rocks under less weight than their ultimate strength when rapidly deformed are in the zone of fracture. (2) Since the boundary between the zone of fracture and the zone of flowage is at a different depth for two rocks of unequal strength, and for the same rock under different conditions of stress, there is a zone of combined fracture and flowage. (3) Rocks buried to such depth that the weight of the superincumbent strata exceeds their ultimate strength are in the zone of plasticity and flowage.

Under the assumption that rocks are porous, and that, therefore, interstitial spaces at a depth are sustained by a column of water extending to the surface, the author calculates, from formulas furnished by Hoskins, that no cavity can exist permanently in even the strongest rock at depths of 10,000 meters or more below the surface. As the development of cavities is a feature of fracturing, deformation with fracture is not possible below that depth. That zone in which deformation occurs without fracture is designated by Van Hise the zone of flowage.[2]

Since rocks vary in strength the depth of the zone of flowage beneath the surface is variable, and where rocks of unequal strengths are interbedded the harder may be in the zone of fracture, the softer in the zone of flowage. It follows that there is a broad zone of fracture and flowage intermediate between an upper zone, in which all rocks fracture, and a lower zone in which all flow.

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[1] Mechanismus der Gebirgsbildung, Vol. II, pp. 3-75.

[2] Since the paper reviewed was written, Van Hise has described much more fully the minute phenomena of the zone of flowage (Bull. G. S. A., Vol. IX, pp. 295-312). According to his recent conclusions, the deformation in this zone includes both microscopical granulation of the mineral particles and their recrystallization. Therefore in this zone he recognizes microscopic fractures and openings.

Gilbert and Dutton, as well as Heim, had anticipated the conclusions of Van Hise in the general recognition of a zone of fracture and a zone of flow, but Van Hise first describes clearly the phenomena of a zone of combined fracture and flow, with which geological observation of structure has chiefly to deal. He contributes also a closer analysis of the phenomena in the uppermost and lower zones. The development of autoclastic breccias, the production of folds by opening of radial joints due to fracture, the association of deformation by fracture and without fracture in the same zone, the adjustments of form by which strata yield to folding, the disappearance of folds in depth, and finally the phenomena in the zone of flowage, are clearly and critically discussed.

The analysis of folds is based upon a classification by de Margerie and Heim, published in 1888, but their ideas are amplified, and a comprehensive classification capable of including all types is developed by the author's recognition of the complex nature of folds. The author's primary classification divides flexures into simple, composite, and complex folds. Simple folds are single anticlines and synclines, which are subclassified in the usual manner as upright, overturned, or recumbent, and as symmetrical or unsymmetrical folds. But Van Hise recognizes that every fold of any magnitude is complicated by minor folds and each of these again by still smaller folds, and so on to microscopic plications of the *n*th order. When thus considered, the major fold may be termed composite. Composite folds of the first magnitude were described by Dana as geosynclines and geoanticlines, and these, as Van Hise points out, are due to combined action of gravity and lateral thrust. In the discussion of composite folds they are classified as normal and abnormal, and the basis of classification is the direction of convergence or divergence of the axial planes of the secondary folds. Thus in a normal anticlinorium the axial planes of the secondary folds converge downward and diverge upward, whereas in an abnormal anticlinorium the axial planes of the secondary folds converge upward and diverge downward. No exception can be taken to this classification as a matter of fact, but as a scheme adapted to instruction or to practical discussion it may not be generally useful, because the mind is speedily confused by the repetition of the terms of upward and downward convergence as applied to anticlinoria and synclinoria of the various normal and abnormal types. Even one tolerably familiar with the aspects of folds must stop to draw a diagram before he can remember what the definition of a given type is.[1]

A definition of normal and abnormal folds, which may appear simpler, may be based on relative dips and depths of folds. It depends upon a law stated by Heim,[2] which is that from a normal anticline a stratum dips more steeply toward that syncline into which it descends to the greater depth. Thereon we may phrase the definition:

A normal fold is one in which the steeper dip is toward the deeper syncline of the same order, whereas an abnormal fold is one in which the steeper dip is toward the shallower syncline of the same order.

This definition has one advantage over that stated by Van Hise. It is related to the initial conditions which determine the positions of folds and their normal or abnormal development, whereas the axial planes are mathematical conceptions only, without actual existence. The relative depths of synclines and the steeper dips are frequently determined in the initial stages of development of folds, and persist as controlling conditions. In any littoral zone the steeper initial dip is usually from the land toward the sea. The resulting steeper dip after deformation holds a corresponding relation.[3]

Van Hise introduces a new use of the common term "monoclinal," in that he applies it to describe "that structure of a mountain mass in which the axial planes of all folds are inclined in the same direction." Discussing "monoclinal structure" he discriminates between overthrust folds and underthrust folds as follows, page 621:

"In monoclinal structure the force, and consequently the movement of the strata have usually been supposed to be more largely from one direction than from the other, and the axial planes of the folds have usually been regarded as dipping toward the force."

After reference to the ideas of H. D. Rogers, Van Hise continues, page 622:

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[1] It has been suggested to me by Mr. L. C. Glenn that a general expression of Van Hise's law of normal folds may be phrased as follows: In a normal fold the axial planes converge centrically with reference to the arc which corresponds to the curvature of the anticlinorium or synclinorium. In an abnormal fold the axial planes converge eccentrically.

[2] Op. cit., pp. 231–233.

[3] Conditions of Appalachian Faulting, WILLIS and HAYES, Am. Jour. Sci., Vol. XLVI, October 1893.

"Folds thus produced by upward differential movement may be called 'overthrust folds.' The axial planes dip toward the effective stress, hence *overthrust folds are those in which the axial planes dip toward the force producing them.* While the development of overthrust folds is the general law, it may not infrequently happen that under favorable conditions the beds or formations may be thrust forward and downward. The folds thus produced by downward differential movement may be called 'underthrust folds.' The axial planes dip away from the effective stress, hence *underthrust folds are those in which the axial planes dip away from the force producing them.*"

The idea of Rogers that deformation proceeded by a wavelike motion, which, in the case of the Appalachians, emanated from the Atlantic region, is firmly fixed in geology without being sufficiently justified by facts. Appalachian structure in many districts presents a monoclinal inclination toward the southeast. If it be overthrust, the effective force operated from that direction. If it be underthrust, the effective force acted from the northwest. There is nothing in the monoclinal relations of folds which will determine that alternative. Theoretically, the geologist is at liberty to infer overthrust in preference to underthrust or *vice versa,* but an hypothesis of the origin of force based upon that inference is of no value. The analysis given by Van Hise leads him to the conclusion that the monoclinal folds and cleavage which prevail in the crystalline areas of the Appalachians are due to an effective force from the southeast, but that conclusion cannot be considered as demonstrated. Indeed, other geologists approaching the problem from a different point of view are justified in reaching the reversed conclusion.

It may be suggested that compression, which causes strata to fold, is a force of gradual accumulation, that is, of such slow growth that the pressure is transmitted through a rock-mass of indefinite extent until movement ensues. Such movement may probably begin at a point determined by local conditions, and may continue in a direction determined by the least resistance either as an overthrust or an under-thrust. In that view the more effective force is simply that which is opposed to the less effective resistance, and the hypothesis of a wave-like influence emanating from a distant source is unnecessary.

Complex folds are defined by Van Hise as those canoes, basins, and domes which result where two sets of folds intersect each other.

The two sets of folds may be produced simultaneously or at distinct epochs by two or more thrusts in diagonal directions or at right angles. Any two diverse thrusts inclined to each other may be resolved into two forces at right angles, which will produce complex folds; if, however, the divergence of the two thrusts is moderate, their effect may be combined to produce a simple system of parallel folds.

Of the two thrusts producing complex folds, one is usually the major thrust, the other the minor thrust, and the system of composite folds to which one or the other gives rise may be described accordingly as the major or the minor system. The length of canoes is proportioned to the difference in power between the major and minor thrusts• If the major thrust greatly exceeds the minor, the complex folds will be long, narrow, and parallel; if the two thrusts are nearly equal the folds will be domes and basins.

As an example of complex folds Van Hise refers to the Appalachian region. The reference, perhaps, requires qualification to modify its general application to the whole province. Districts of New England and North Carolina do exhibit complex folds which are markedly developed in the direction of the minor as well as of the major thrust, but in the Appalachian Valley region from New York to Alabama the folding scarcely appears to be complex. Van Hise cites the undulatory pitch of the axes as evidence of a pressure from northeast to southwest. The pitch is to some degree due to variations of initial dip and the depression of synclines in folding. There is no crenulation of the major strikes such as might be expected to result from a transverse thrust. If this zone of typical Appalachian structure shall be shown to be complex in the sense in which Van Hise defines the term, there will be good reason to assume that complex folding is the general rule. This may probably be so.

Van Hise's extensive experience in the study of complex structure enables him to suggest practical methods as to the manner of determining whether the rocks of the district are complexly folded and in what manner. These suggestions relate to the manner of making certain necessary observations, which he sums up as follows:

1. "Determine the strike and dip of the strata at the given point. These give the resultant position of the strata as tilted by the force. of folding in both directions."

2. "Determine the direction of the pitch of the axes of the major folds. The first is the direction of dip, and the second is the amount

of dip of the minor or cross folds. The average strike is therefore determined."

3. "Determine the direction and pitch of the axes of the minor folds. The first is the direction of dip, and the second the amount of dip of the major folds. The average strike is therefore also determined."

Van Hise correctly observes that of these three observations the first is the only one ordinarily taken, and it is the one of least importance in regions of close complex folding. It becomes obvious in considering his practical suggestions that a thorough knowledge of the physiography of the region and the relation of relief to structure is quite as important for the solution of complex folds as is a knowledge of the rocks.

Concluding the section relating to folding, Van Hise considers the value of differential folding as an evidence of unconformity, when not sustained by other phenomena. A discordance in the flexures of two adjacent formations is only to be absolutely relied upon as evidence of unconformity when the structural discordance is so marked that the earlier series exhibits a relatively complex structure as compared with that of the later series.

In Section III Van Hise considers cleavage. He grasps hypotheses of the origin of cleavage advanced by other geologists from Phillips to Becker, discriminates between them, amplifies their basis of fact by his own extensive observations of the crystalline schists, and states those conclusions which he finds valid. He defines *cleavage* in a strict sense "as a capacity present in some rocks to break in certain directions more easily than in others." This use of the term is that in which it is applied to minerals. He distinguishes fissility as a phenomenon secondary to cleavage, fissility being "a structure in some rocks by virtue of which they are already separated into parallel laminæ in a state of nature."

Citing microscopical study of cleavable slates and schists, Van Hise concludes (page 635) that:

"Rock cleavage is due to the arrangement of the mineral particles with their longer diameters or readiest cleavage, or both, in a common direction, and that this arrangement is caused, first, and most important, by parallel development of new minerals; second, by the flattening and parallel rotation of old and new mineral particles; and third, and of least importance, by the rotation into approximately parallel positions of random original particles."

From these observations follows the inference that cleavage develops in a plane normal to the pressure. The grounds for this inference are discussed at some length and the author's opinion is finally stated (page 639):

"I therefore conclude from analysis, from experiments upon viscous and plastic bodies, from observations in the field, and from studies with the microscope, that I am justified in the statement that the secondary structure of a rock which is deformed by plastic flow develops in the plane normal to the greatest pressure, and that this structure is true cleavage."

From the observed parallelism to the inferred normal relation to pressure is a step in hypothesis. To this extent the conclusion falls short of demonstration, but it is in accord with the opinions of eminent students on cleavage, and is supported by mathematical analysts, with one marked exception. The exception is Mr. Geo. F. Becker.

It has been maintained by Becker that cleavage always develops in two shearing planes at angles to the pressure. His method of arriving at this conclusion may best be indicated by a quotation from his article:[1]

"In the following pages the attempt will be made to develop all the manifestations of uniform or homogeneous finite strain in rock-masses regarded as isotropic, exhibiting viscosity and capable of flow, which can be elucidated without assuming a law connecting stress and strain. For this purpose finite strain must first be discussed by itself; then it must be considered just how far the relations of stresses are capable of coördination with those of strain. The influence of viscosity and solid flow must next be shown. Readers willing to assume that these subjects have been logically treated will probably skip them and proceed to the geological applications which follow. Finally, the results will be compared with actually observed phenomena and with the experiments which several investigators have made on slaty structure."

The method followed by Van Hise is that of induction from the facts, whereas Becker pursues that of deduction from general principles. Van Hise does not deny the validity of Becker's reasoning nor its general application. He describes the development of fissility and jointing in the zone of fracture as in accordance with Becker's view. But he concludes that in the zone of flow another process is effective to product cleavage; namely, special orientation of minerals and particles.

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[1] Finite Homogeneous Strain, Flow, and Rupture of Rocks, by G. F. BECKER, Geol. Soc. Am., Vol. LV, 1891, p. 16.

Fissility is defined by Van Hise as a parting of a rock along shearing planes, which corresponds with the structure described by Becker as cleavage. It is obvious that a capacity to part in a certain plane (Van Hise's cleavage) may often coincide with an actual parting developed later. If the capacity to part be a structure developed in the deep zone of flow, it is most probable that the actual parting should be developed in rising through the zone of fracture, as any rock mass must to become accessible to our observation. Hence arises the opportunity for confusion of the two structures, according to Van Hise, but discriminating the one from the other he concludes that: "Fissility developing in the shearing planes is usually secondary to cleavage which developed in the normal planes."

The relations of cleavage and fissility to bedding and to folds are discussed at length, and the value of these structures as criteria for determining unconformities are stated and limited.

With reference to joints Van Hise's discussion is along lines logically consistent with his views of folding and also of fissility. Tension joints may be produced radially to the curvature of folds; this phenomenon he rightly considers important as a means of accommodation to curvature in the zone of fracture. Compression joints develop in shearing planes, usually in two directions, and when associated with simple folds generally parallel to the strike. When folding is complex different sets of shearing plains may correspond to strike-joints and dip-joints, but the association of three or more joint systems may probably be the result of several orogenic movements.

Faults also are classified as tension faults and compression faults, but recognizing the dominant influence of gravity or of thrust respectively, Van Hise well prefers to distinguish them as "gravity" faults and "thrust" faults. The former is equivalent to the old term "normal," the latter to the inaccurate designation "reversed" fault.

In discussing the relation of faults to folds it is stated that under moderate load thrust faults may result as clean cut fractures, whereas under greater load they may be associated with overfolds, and at still greater depths overfolds may develop without thrust faults.

"This statement might be well supplemented by the further explanation that folds may give place to thrusts on diagonal planes in the deep zone of flowage. Two conditions are essential to folding;

first, that the stratum shall be sufficiently rigid to transmit a maximum stress in a definite direction ; and second, that movement on bedding planes shall afford a means to adjustment to curvature. It is an open question how far these conditions are effective in a deep zone of flow. In the opinion of the reviewer neither of them exercises a dominant influence. Distinctions of stratification may become insignificant under excessive pressure, and great friction on bedding planes may prevent accommodation, and the mass may be deformed by dislocation in the diagonal planes. This is illustrated in model J, Plate XCIII, stages *f* to *k*, "Mechanics of Appalachian Structure." The accommodation of the soft material to shortening in one direction and elongation in another is there accomplished by the reciprocal displacement of wedges, which are defined by planes diagonal to the applied force. This explanation is briefly suggested by Van Hise in a subsequent paragraph on the depth of the zone affected by faults, but he fails to emphasize the idea that while thrusts developed in the zone of fracture pass into folds below, folds in turn may be replaced by thrusts at still greater depths. The relation is important."

Comparing the effect of few great structures with that of numerous small ones, Van Hise concludes :

"The average deformation of a region may be the same whether it be by a few great faults with little or no fissility, by more frequent lesser faults with or without fissility, by faults and overfolds with or without both cleavage and fissility, or by folding with or without faults and cleavage ; also that there is every gradation between faulting and fissility, and probably every gradation between faulting and cleavage."

In Section VI, Van Hise discusses dynamic breccias and pseudo conglomerates under the generic term of "autoclastic" rocks, which was first used by H. L. Smyth. The development of autoclastic rocks is limited to the zone of fracture and they are not of common occurrence in strata younger than the Cambrian. But where they occur in rocks which have undergone repeated disturbances the resulting dynamic breccia may so resemble a basal conglomerate as to lead to an erroneous inference of unconformity. In the discussion of these cases Van Hise inadvertently illustrates with what remarkable care and patience the geologic study of the Marquette district has been pursued.

Metamorphism is treated in sections VII and VIII, with the purpose "briefly to sketch a few of the more important processes which have affected large areas of the pre-Cambrian rocks of North America." The author recognizes pressure, heat and chemical affinity as the prominent forces producing metamorphism. When pressure is resisted by rigidity, *i. e.*, produces only molecular motion, the result is static metamorphism ; when pressure passes into mass motion the result is dynamic metamorphism. The chief processes considered are consolidation, welding, cementation, injection, metasomatism, and mashing.

In discussing cementation and injection the author takes up the origin of pegmatites and says :

"It seems to me that to adequately explain all the facts of pegmatization described in various regions of the world, we must conclude that all three processes have been at work — in some cases igneous injection, in some cases aqueo-igneous action, and in other cases pure-water cementation, and in still others combinations of two or all of these processes. It is further believed that there may be no sharp separation, but, on the contrary, all gradations between the three — that is, it is thought highly probable that under sufficient pressure and at a high temperature there are all gradations between heated waters containing mineral material in solution and a magma containing water in solution. In other words, under proper conditions water and liquid rock are miscible in all proportions. From the water solutions true impregnation or cementation would take place; from the rock solutions, true injection. Pegmatization may comprise these and the intermediate processes."

Metasomatism is described with reference to (1) "alteration of original mineral particles, (2) minerals produced by alterations, and (3) texture of rocks produced." The brief statement of facts familiar to petrographers suggests also brcader aspects of comparative petrology.

"Mashing is a term here introduced with a specific meaning. It is used to designate by a single word that complex process which involves shortening without change of volume, or simple shearing, or a combination of the two. Mashing implies all the other special processes of metamorphism."

Having thus considered in general the processes of metamorphism, Van Hise classifies metamorphic sedimentary rocks according to those processes which have been particularly effective in the development of each class. The enumeration of rock types in relation to conditions affecting their development is particularly valuable.

Metamorphic igneous rocks are treated separately, though briefly, but the means of discriminating between originally sedimentary and originally igneous rocks are discussed with the insight due to broad observation. The difficulties of discrimination are suggested in the following statement:

"It has been seen on previous pages that a large number of kinds of schists and gneisses may be produced by the metamorphism of sedimentary rocks; also it has been shown that similar crystalline schists may be derived from igneous rocks. It is further certain that a schist or gneiss may be derived partly from sedimentary and partly from igneous rocks. For instance, a metamorphosed fissile sedimentary rock, such as mica-schist or mica-gneiss, may be injected in a complicated way parallel to the planes of schistosity, and thus produce a banded gneiss, part of which is igneous and part of which is sedimentary. The rock may be predominantly of either one of these materials. If the injected sedimentary rock be subsequently folded, this will produce differential movements parallel to the banding, and the igneous and aqueous bands may be merged into one another and have structures so similar that it is impossible to determine what part of the rock is igneous and what part aqueous. The Manhattan schists of southeastern New York, and especially near Long Island Sound, are a perfect illustration of a gneiss produced by the extreme metamorphism of a sedimentary schist and the subsequent parallel and cross injection of granitic material.

"From the foregoing it is clear that an inseparable schist or gneiss formation may be produced from altered intrusive rocks, from altered lavas, from altered tuffs, from altered sediments, and from any possible combination of two or more of these.

"Doubtless, in regions in which the gneisses are of a very complex character, a number of the processes mentioned in the previous pages, and possibly others unknown, must be united in order to explain all of the phenomena."

Stratigraphy, *i. e.*, the sequence of formations, is deduced for pre-Cambrian rocks from observations of the phenomena of structure and metamorphism and other relations in detail. It thus becomes an inference instead of being a primary fact of observation, as it may be in rocks which are less disturbed. Van Hise, therefore, gives stratigraphy a logical position at the close of his discussion of principles. The evidences of stratification which are obvious in unaltered series may be so obscured in older rocks as to be determinable only by the closest observation. Hence, bedding, ripple marks, basal conglomerates, and phenomena indicating unconformity afford material for extended consideration.

This review would be made too long by detailed references to the second part of the "Principles," which treats of the historical geology of the pre-Cambrian time. The discussion is arranged according to districts and for each district the principle most saliently illustrated is emphasized. This part of the book constitutes a valuable summary of existing knowledge and a convenient and reliable reference.

The style of the author is the expression of complete knowledge of his subject, combined with exuberance of thought. Another great writer, whose works are characterized by brilliancy and clearness, recently said: "When I undertake to write a book I endeavor first to see what I can exclude from it, and after the process of rigid exclusion I carefully arrange the surviving ideas even to the order of paragraphs before I write." The thoughts which rush upon Van Hise are related in so many directions that many associations of the idea seek expression at once. His book would be easier to read and not necessarily less accurate, if the thought were stripped. The logical analysis is consistently carried out for all the major headings, but it is not adequately extended to the paragraphs and sentences. Nevertheless, a thorough study of the work leaves a profound impression of the earnest purpose with which it has been conceived and of its value as a contribution to one of the most difficult branches of geologic science.

BAILEY WILLIS.

Topographic Atlas of the United States. Physiographic Types by HENRY GANNETT. Washington: U. S. Geological Survey, 1898.

The enlightened policy adopted by our national Geological Survey of encouraging as wide a use as possible of the material gathered at great expense receives a new and welcome illustration in the publication of the first folio of the above named series. It presents ten maps as "illustrations of some of the simplest and most characteristic types of topography to be found in those parts of the United States which have been thus far mapped. Succeeding folios will illustrate more complex forms." The origin of the atlas was in a proposition of the